USE OF A BUILDING ENERGY MODEL TO PREDICT ENERGY UTILIZATION INDEX: A COMPARISON

A Thesis

by

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ABSTRACT

Qatar has one of the highest rates of infrastructure and general construction spending and growth in the world. Quarterly estimates for Qatar's gross domestic product growth are on the order of 15 – 17% (Trade Economics, 2015). This growth has impact on the power and water infrastructure in the country and as a result Qatar is trying to address the associated sustainability issues. Though new construction is an obvious target, the existing building stock has an impact and will continue to draw on resources for the life cycle of those structures. But the lack of understanding of complex building energy modeling tools constrain building owners from using them to monitor their building's energy performance. On the other hand, less complex simulation tools like eQUEST heavily rely upon input data and logical assumptions for their accuracy. An energy model using eQUEST of an office building in Doha was validated against utility data and a peer model to understand the key factors that determine the accuracy of the model. The study showed that the total electricity consumption decreases by 3% on average as the lighting (LPD) is reduced by approximately 20%. For occupancy, the electricity consumption increased by 8% per increase of 50 ft^2/ person (4.64 m^2/person) in occupant density. For operational schedules, the results indicated an average increase of 22% in total electricity consumption per incrementing day. Lastly, changing the weather file in the model from Doha to Houston, resulted in a 3% increase in the total electricity consumption.

ACKNOWLEDGEMENTS

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I would also to thank my friends, the department faculty and staff for such a great experience here at Texas A&M.

Finally, thanks to my parents and my brother and sister-in-law for their encouragement and support at every step.

NOMENCLATURE

AESG	Alabbar Energy and Sustainability Group
DOE	Department of Energy
DOE 2.1	Department of Energy (Software) 2.1
EC	Electrochromic
ECM	Energy Conservation Matrix
EUI	Energy Utilization Index
GCC	Gulf Cooperation Council
GDP	Gross Domestic Product
GSAS	Global Sustainability Assessment System
HVAC	Heating, Ventilation and Air Conditioning
KPI	Key Performance Indicators
LEED	Leadership in Energy and Environmental Designs
LPD	Lighting Power Density
mEUI	Modelled Energy Utilization Index
NCEI	National Center for Environmental Information
QSAS	Qatar Sustainability Assessment System
USDOE	United States Department of Energy
Visual DOE	Visual Department of Energy (Software)

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CHAPTER I

INTRODUCTION

Approximately 40% of the total energy around the world is consumed annually by existing buildings alone (USDOE, 2012). This level of energy consumption is truly not sustainable. It is becoming clearer every day that reducing building energy use is crucial in order to curb global climate change trends. Countries like Qatar, UAE, India, and China are growing at very high rates of GDP with the coincident energy needs to sustain this growth. Since 2004, Qatar's population has more than doubled, largely because of expatriate immigration. According to the Qatar Statistics Authority, the country's population in December 2014 was 2,116,400. Of that population, approximately 300,000 are Qatari nationals. The remaining population are expatriate workers, providing both highly skilled (white collar) and manual (construction) labor. During the past decade, the tendency has been to build all at once without full thought of how to occupy it. As a result of this growth and change from a small, inconspicuous country, to a regional economic power, the country is becoming environmentally unsustainable.

Existing buildings in Qatar are, in general, running unsustainably and inefficiently resulting in excessive carbon footprints (Ayoub, 2014). With energy being supplied to Qatari citizens at highly subsidized rates, or free, incentives for reducing energy use are virtually non-existent. On the other hand, there are Qatari governmental agencies that realize that encouraging reduction in energy consumption could reduce the 15.4 percent of the total governmental budget, which is currently spent on energy subsidies in Qatar (Espinoza, 2013). Many of the GCC countries are implementing energy codes in an effort to address the energy consumption in their respective country.

In the interest of accomplishing this energy reduction, it is important to understand and analyze how existing buildings are performing. Building energy analysis for new construction is fairly standard in modern design. This is not the case with existing buildings. In either new or existing building energy analysis, a powerful technique is available to both designers and owners. Building energy modeling with programs such as EnergyPlus (USDOE), eQUEST and numerous commercial products enable the designer or building owner to develop a model to predict energy performance for their building. Building energy performance can be compared with the original design intent using these methods and then calculating an Energy Utilization Index (EUI), which is expressed as energy used per unit area per year (for example $kWh/m^2/yr$ or $kBtu/ft^2/yr$). Another tool that can be used is Benchmarking. This technique is useful when comparing building energy performance across sectors. For example, how does the EUI for a building in Doha, Qatar compare to a similar building in Houston, Texas? In addition, the energy use profile of the given building can be compared to the performance of similar buildings under similar conditions (Wang, 2015).

CHAPTER II

REVIEW OF LITERATURE

2.1 Building Performance

It is well established that a building's energy performance relies upon parameters such as local climate, HVAC system type and efficiency, lighting, building envelope, management team, occupancy, occupant behavior etc. A building is a complex facility with numerous components contributing to its energy consumption. Making changes in these components can result in a significant difference to the building's energy performance. To understand how building components like windows impact a building's performance, Tavares et al. (2014) analyzed electrochromic (EC) windows in Mediterranean conditions. An energy simulation tool was used to compare how EC windows perform as opposed to single glazed windows. It was concluded that EC windows indeed reduced energy needs and provided a tighter building envelope. Other key performance indicators such as lighting were explored by Onaygil (2009). Her paper provided a comprehensive study of efforts undertaken by the Turkish government in recent years to implement better lighting regulations to increase energy efficiency in facilities.

Apart from building materials, another important factor that affects building performance is occupancy. Yang et al. (2014) focused on using personalized occupant profiles in HVAC schedules to save energy as compared to the conventional schedules. Martinaitis et al. (2015) studied the impact of occupancy information while performing energy model simulations for houses. The results indicated that using different occupancy profiles in parametric runs of the simulation model, leads to changes in the total energy performance.

Wang et al. (2012) outlined the importance of factors such as weather and building operational schedules in the energy performance of medium-size office buildings. The findings of this study indicated that yearly weather fluctuations result in -4% to 6% change in energy consumption. While the operational parameters can cause uncertainties in the range from -28.7% to 79.2%. Zhao and Magoulès (2012) extensively reviewed various developed models like neural networks and engineering methods like energy models to analyze the impact of various factors such as weather, occupancy, HVAC etc. on a building's performance. However, they concluded that any judgment on which method is better at predicting energy consumption, is difficult until comparisons are made under same circumstances.

2.2 Building Energy Modeling

Building Energy Modeling is performed with simulation software that takes into account building attributes such as total floor area, envelope construction, and HVAC system type in order to analyze the performance of a building. Energy managers performing Building Energy Modeling use software such as EnergyPlus, DOE 2.1 and eQUEST among others (Crawley et al., 2008). Energy Modeling can provide a ‘report card’ of a building, which can also help the owner in obtaining sustainability certification such as that required by LEED. However, simulation software such as EnergyPlus is known to be extremely complex and requires significant effort to understand and implement (Rallapalli, 2010). Also, these programs require detailed data, which can prove difficult to obtain for design as well as existing buildings. However, there are simpler simulation tools available in the market such as eQUEST®, which is a software package based on the DOE-2 simulation engine, but is simplified in its interface and provides a more rapid access to model building. Rallapalli (2010) compared the two prominently used simulation tools EnergyPlus and eQUEST to determine the pros and cons of both. The results concluded that EnergyPlus lacks a user-friendly interface and is complex and exhaustive, which limits its usage for building energy performance simulation while eQUEST® is faster and easier to use, with a better and more user-friendly interface generating outputs which could be easily understood and analyzed by non-experts too.

Energy modeling has increasingly been used to forecast the energy impact of specific design decisions and to assist in the making of those decisions (Crawley et al. 2008; Salisbury and Diamond 1998; US DOE 2011a). Ryan and Sanquist (2011) explored the importance of building occupancy in the accuracy of Building Energy Modeling. Raftery et al. (2011) tried to link the source of information used to make changes to the initial model in developing the final energy model of the building. This has helped future users in reviewing the changes made through the whole process by providing the access to the source evidence. Ioannou (2015) emphasized how simulation tools falsely assume occupancy and occupant behavior thus giving out inaccurate results. Also, his research found that the effect of building parameters was dominated by occupant behavior and their thermostat use. The growing concerns over excessive energy consumption and inefficient building management have been stated by Lombard et al. (2008). Lombard also focused attention on improving the understanding of HVAC systems to synthesize energy efficiency in non-residential buildings. This also assisted policy makers in the improvement of HVAC performance in their buildings.

2.3 Energy Utilization Index

Energy Utilization Index (EUI) is an important aspect of this study. An EUI is the energy used by a building measured per unit area per year. A building's EUI is directly proportional to the intensity of energy usage. EUI has been considered the performance index of a facility in previous studies. Akbari et al. (1994) designed a technique for estimating end-use load shapes for predicting annual EUIs for commercial buildings. Agdas et al. (2015) proposed the Assessment of EUI across a university campus under their Sustainable Energy Policy. The EUIs of 10 LEED and 14 non-LEED certified buildings were calculated and statistical significance was analyzed. Surprisingly, it was found that there were no statistically significant differences in the building's energy performance between certified and noncertified buildings. The Cornell University campus has presented a prime example of aggressive approach towards energy conservation. In 2011, the Cornell University Energy and Sustainability department began monitoring EUIs for various building units and set targets to improve them. Steam, chilled water and electricity EUI have been closely monitored since and graphically plotted to present an analysis of the performance of building units on campus.

2.4 The Qatar Problem

The latter half of 1990s decade saw the discovery of gas in Qatar, which proved to be the major driving force behind aggressive government investments and planned construction projects across both public and private sectors. His Highness Sheikh Hamad bin Khalifa Al Thani established the Public Works Authority "Ashghal" in 2004, which administered the development and urban growth in Qatar. Soon after the success of the 2006 Asian games, Doha's West Bay skyline was proposed which further led to more rapid construction (Mahgoub and Abbara 2012). Bible (2011) analyzed this problem and designed a building energy performance report for the Texas A&M University at Qatar building using EnergyPlus and also suggested methods to improve energy efficiency for institutional buildings. Ayoub et al. (2014) also studied how energy could be conserved in commercial buildings in Qatar by implementing an Energy Conservation Matrix (ECM) to analyze the implementation of various energy conservation alternatives for improving the overall building efficiency. It was estimated that 7.5% of energy was conserved by redesigning the building envelope, while energy reduction due to occupant behavior changes ranged from about 2% to 16%. The conserved energy potential integrating both customer behavior and envelope redesign was from 10% to 24%. These scenarios would also help in bringing down CO_2 emissions which, according to the author, would provide motivation for building owners in Qatar to move towards sustainable construction and efficient building management.

Apart from hosting the 2022 FIFA World Cup, Qatar has also issued an economic, social, human and environmental development blueprint known as Qatar’s National Vision 2030. As a result of these unprecedented growth aspirations, the Qatar government has started to feel the need to improve energy usage patterns and construction practices in the country. By developing certification systems like the Qatar Sustainability Assessment System (QSAS), which would eventually be enforced as a part of building code, Qatar looks to implement better energy standards and practices in its industry by implementing similar methods as the Department of Energy (DOE) in United States.

CHAPTER III

PROBLEM AND RESEARCH SETTINGS

3.1 Problem Statement

Modeling building energy performance is a common technique especially when used for commercial buildings. However, validation of a building's EUI as determined from the building energy model is problematic. Ideally, the model EUI can be validated through comparison with an existing building's actual energy usage report (utility bills). Validation is further complicated when using software tools like EnergyPlus because these programs require extensive user inputs, and have a steep learning curve. Generally, building owners or the facility management team, lack the depth of understanding for use of these detailed modeling programs. It is proposed that a simplified building energy modeling program could allow the development of a reliable estimate for the EUI for a subject building. With a validated model EUI, the owner has a baseline performance available with which actual building energy use could be compared.

Although some energy modeling software are easier to use than others, each still relies upon the input specifications provided by the user. Any inaccurate information can create differences in the predicted energy performance and building's actual energy use.

Thus, the sensitivity of modeling software to important Key Performance Indicators (KPI) needs to be analyzed and tested.

3.2 Research Objective

The research consists of a qualitative case study of an existing high-rise office building located in Doha, Qatar. A simplified energy model will be validated with actual building energy use and an owner provided peer model for this office building. This comparative analysis will provide a validated baseline model which can be used to test the sensitivity to the key performance indices (KPI).

The following are milestones for this research:

- Simplify the building energy modeling process for owners/facility management.
- Develop KPI that will result in an accurate and reliable estimate of facility EUI.

3.3 Assumptions

The following assumptions are made regarding this study:

- Utility data provided for the case building are accurate.
- Construction and operational details of the building are accurately described.

3.4 Research Limitations and Questions

Although building energy modeling and energy performance analysis are common engineering and design tools for buildings and have wide application, this study is specific for a high-rise office building in Qatar.

The research will address the following questions:

- Is the subject building performing as well as the model predicts? If not, what might be the reasons for this?
- Is it possible to extend the results from the simplified model developed in this study in other climatic locations?
- How do the KPI for the building affect the building's energy performance?

3.5 Research Significance

As building energy modeling software has grown more powerful, the sophistication of these programs has also grown. These programs now take considerable training and operational experience before reasonable building energy models can be produced. If the important key input parameters can be identified that lead to an accurate and reliable EUI estimate, then the owner/facility management team will have a useful tool with which to benchmark energy consumption and management of energy in a building.

CHAPTER IV

RESEARCH METHODS

4.1 Introduction

Building energy modeling, as mentioned in the previous chapters, is a comprehensive method of evaluating a building's performance. This complex and time consuming process of generating a performance report was somewhat simplified by eQUEST, a software which runs on a DOE simulation engine and presents a graphically simpler and user-friendly interface. However, considering eQUEST requires fewer inputs as opposed to its more comprehensive counterparts such as EnergyPlus, it is more sensitive to user input parameters. If not accurately entered in the software, the predicted building performance may significantly differ from the actual building performance. Hence, in order to improve the accuracy of modeled predictions and determine error sources, it is important to evaluate how sensitive the energy models are to different input parameters. (Azar and Menassa 2012).

In order to achieve the desired objective, a three step methodology was adopted. In Step 1, a detailed energy model for the case building was prepared using building specific inputs (refer to Appendix A) provided by the building's facility management department. Next, the software generated a monthly total energy consumption report, which was summed for the entire year of 2013 and compared against the actual metered data for that year. Typically, a building energy model produces hourly energy consumption for a given building. This hourly data can be aggregated for the whole year to calculate the modeled EUI (mEUI). The study building's mEUI was calculated and compared to validate with the actual EUI calculated from the metered data.

In Step 2, the eQUEST model was validated by comparing it with a *Visual DOE 2* energy model that had been provided to the building owner as part of the LEED certification process. This comparison also identified the relative accuracies of pre-occupancy (Visual DOE) and post-occupancy (eQUEST) energy modeling simulation results. The expected validation range was assumed to be ± 15% of actual EUI (Maamari et al., 2006).

As noted in the literature review, fewer inputs are needed in order to produce a model in eQUEST versus EnergyPlus, the relative importance of those inputs are higher in eQUEST. Hence, in Step 3, the four parameters identified as the KPIs namely lighting, occupancy, climate and schedule are altered in the baseline model and rerun parametrically. The parametric run results are generated, compared with baseline and actual EUIs and graphically analyzed.

4.2 Building Description

The case building selected for this research is a 57 story high-rise office building located in the West Bay area of Doha, Qatar. It is a North-east facing office facility with a cumulative conditioned building area of 578,616 ft^2/ 53755.2 m^2. The total building height is 805 ft./245.36 m and the primary occupant is the RasGas Company Ltd. in the perimeter tenant area. Al Dana is the owner of the building and utilizes the core area. A satellite image of the case building is displayed in Figure 1 for reference. (Source: Google Earth)

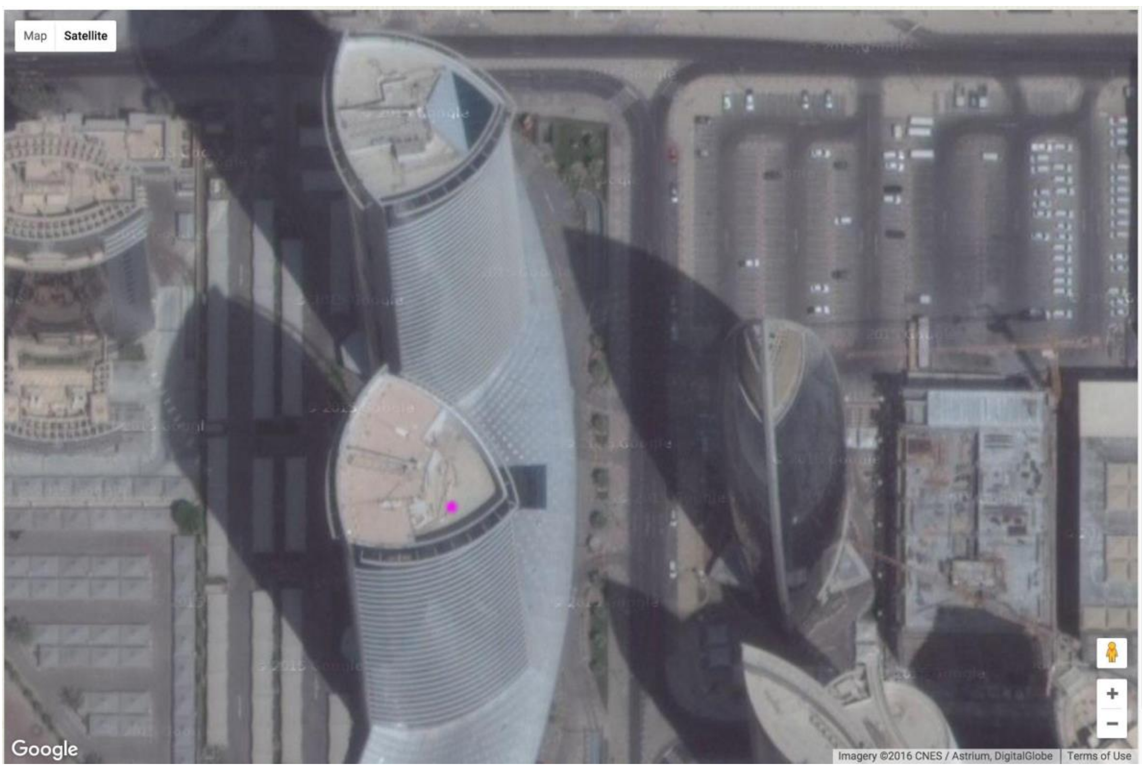

Figure 1: Satellite Image of the Case Building- RasGas Tower, Doha, Qatar (Source: Google Earth)

4.2.1 Building Material and Envelope

The exterior walls of the building are 6”/152.4 mm heavy weight concrete with R-12 polystyrene insulation. The floor is also 6”/152.4 mm concrete base with ceramic/stone finish. The internal walls are ½”/12.5 mm drywall/sheetrock framed on metal studs with insulation on select interiors. The building is operated under positive pressure, which eliminates any potential envelope infiltration. A screenshot of the eQUEST wizard screen for inputting building material and envelope details is displayed in Figure 2.

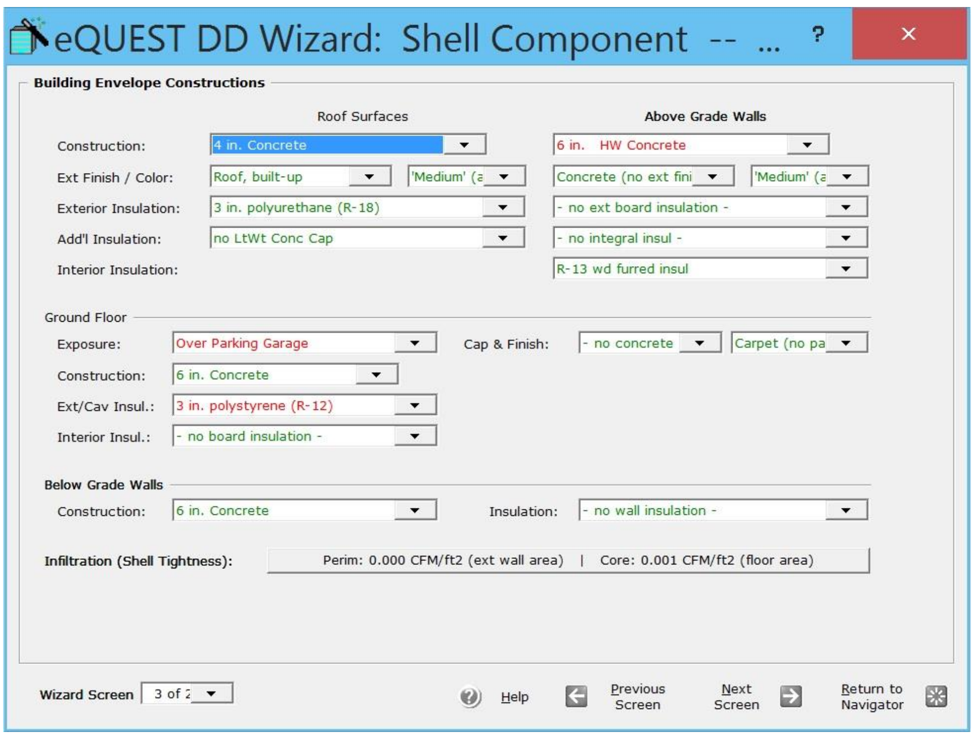

Figure 2: Screenshot of Building Envelope Wizard Input Screen in eQUEST

4.2.2 HVAC

The building is supplied chilled water by the district cooling system Qatar District Cooling Company also known as Qatar Cool. Qatar Cool owns and operates three cooling plants in Doha providing 197,000 tons/200161.24 metric tons of combined refrigeration capacity, which is one of the largest in the world (Qatar Cool, 2016). The building air conditioning is primarily a standard VAV/chilled water system with electric reheat system at the VAV distribution boxes. The domestic hot water is provided by a domestic hot water supply loop connected to central hot water pumps. More information is provided in Appendix A. The typical HVAC zoning in the building is shown in Figure 3 below.

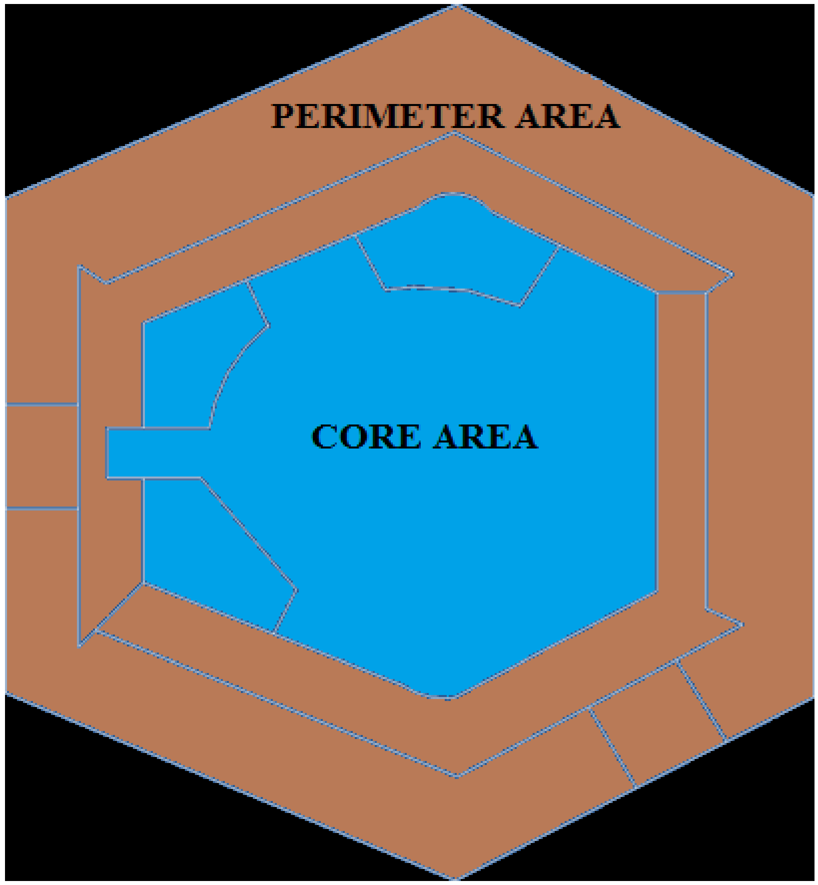

Figure 3: HVAC Zone As Drawn in AutoCAD (Source: Coombes, 2012)

4.2.3 Building Schedules

The building is in operation 5 days a week from Sunday through Thursday. The occupants generally begin to enter at around 6am and leave at 6pm. The building is closed on Friday and Saturday as well as on local holidays. However, the building is air-conditioned throughout the year 24x7. A typical schedule input screen for eQUEST is shown in Figure 4.

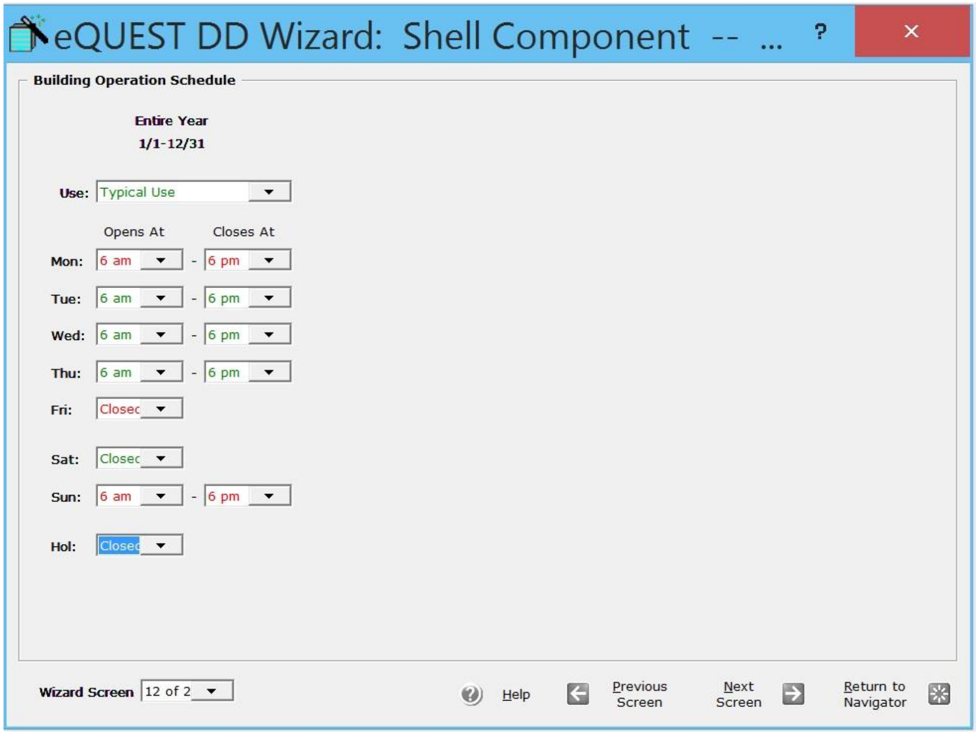

Figure 4: Screenshot of Building Schedule Wizard Input Screen

4.2.4 Data Collection

The building specifications (shown in Appendix A) were obtained from the facility management department of the building. The weather data for Doha was purchased from a weather file providing company called White Box Technologies, which gathers historical weather data as recorded and made available by the National Center for Environmental Information (NCEI).

4.3 eQUEST Model

For modeling the building energy output, eQUEST Version 3.65 was used in this study. Within eQUEST, the DOE-2.2 simulation engine performs an hourly simulation of the building with inputs on building envelope, orientation, HVAC zones, walls, windows, occupants, plug loads, lighting etc. These are all inputs that are available to the user to alter. The simulation uses appropriate default values for building specifications not known to the user. The software can also evaluate the performance supply and return fans, chiller pumps, boilers and other energy-consuming devices. Another important aspect of eQUEST is its usability in creating multiple parametric simulations and comparing the alternative results graphically. Cost estimates and savings can also be computed by inputting provided utility rates (eQUEST, 2008).

The case study energy model was developed in the Design Development Wizard, which provides more flexibility to user inputs as compared to the Schematic Design wizard of eQUEST. The program provides wizard input screens for HVAC systems, building envelope and general building information having default values, which can be changed by the user. Once the user goes through all these wizard screens, he can direct the program engine to perform the simulation. Once the simulation is completed, the program provides a screen that identifies any errors, if any. If no errors are found, the user can generate the output report. Using these program simulation directions and building specifications, the baseline energy model for the case building was generated. Figure 5 shows the general information wizard screen in eQUEST, which is the first screen to be prompted during modeling inputs.

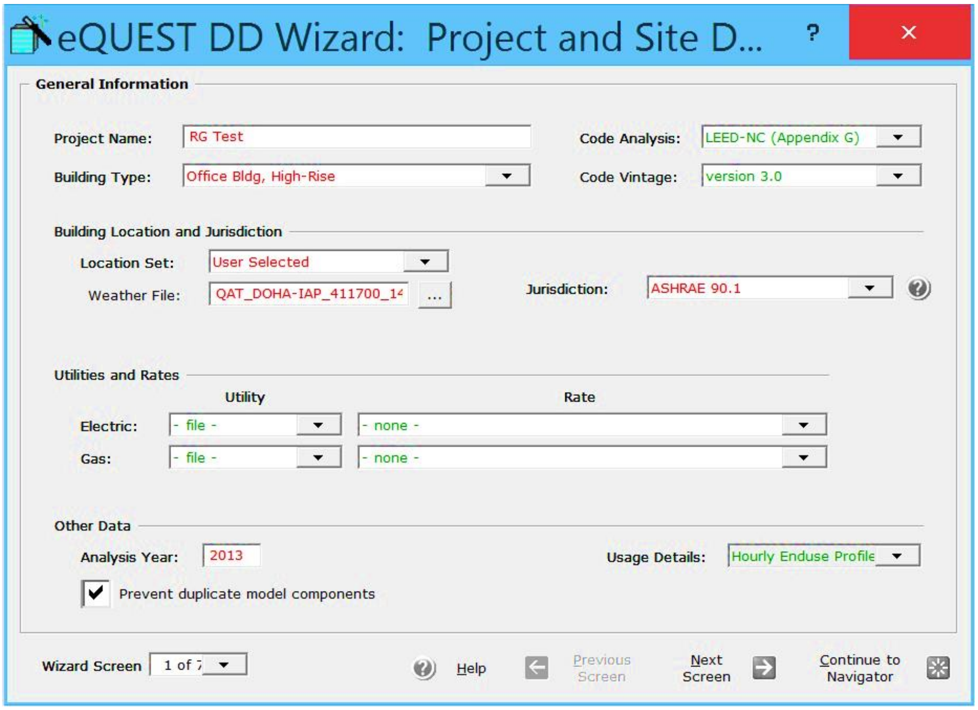

Figure 5: Screenshot of General Information Wizard Screen in eQUEST

After generating the baseline energy model of the building, the analysis of the output is done using a 3 step comparison method. The details of this method are provided below.

Step 1: Actual Metered Data Comparison

The monthly electricity and chilled water consumption for the case building for the year 2013 was provided by the facility management department of the building. The EUI was calculated for the entire year by dividing the total energy consumption in one year for the building (in kBtu/Kwh) by the total conditioned area (in square feet).

Step 2: Peer Model Comparison

In this part of the study, a comparison is drawn between actual metered data, the eQUEST simulated baseline model data and peer data from an alternative energy model for the same case building in order to juxtapose all three results and analyze their relative accuracy.

In January 2012, a Dubai based energy-consulting firm Alabbar Energy and Sustainability Group (AESG) provided an energy modeling report for the RasGas building to analyze and identify potential energy savings to achieve the minimum 15% energy savings for compliance with LEED Commercial Interiors Credit EAc 1.3 (Coombes, 2012). The monthly energy consumption as predicted by this Visual DOE software based model is provided in Table 1 below.

Table 1: Visual DOE Peer Model Predicted Total Energy Consumption (Source: AESG)

RasGas Energy Model

Technical Note: Final Energy Modelling Report

AESG

ALABBAR ENERGY & SUSTAINABILITY GROUP

Proposed Design Case:

	AREA LIGHTS	MISC EQUIPMT	SPACE HEAT	SPACE COOL	HEAT REJECT	PUMPS & MISC	VENT FANS	DOMHOT WATER	EXT LIGHTS	TOTAL KWH
JAN	219,825	433,092	5,772	294,069	26,980	92,281	105,342	2,412	2,104	**1,181,875**
FEB	199,402	392,872	4,275	275,887	24,838	88,105	101,344	2,269	1,900	**1,090,892**
MAR	236,906	467,574	1,205	363,207	29,782	123,766	109,735	2,661	2,104	**1,336,939**
APR	211,656	416,875	74	398,929	28,207	150,296	108,411	2,376	2,036	**1,318,858**
MAY	228,365	450,333	0	498,300	30,889	201,170	129,137	2,359	2,104	**1,542,657**
JUN	227,251	448,421	0	558,302	32,005	229,093	139,373	2,152	2,036	**1,638,632**
JUL	212,769	418,787	0	602,981	32,244	245,958	135,598	1,910	2,104	**1,652,352**
AUG	236,906	467,574	0	710,902	36,983	285,587	146,839	1,976	2,104	**1,888,870**
SEP	211,655	416,875	0	577,588	32,263	233,423	127,641	1,789	2,036	**1,603,269**
OCT	219,825	433,092	0	511,344	31,168	205,599	121,336	1,934	2,104	**1,526,402**
NOV	210,170	413,939	240	375,805	27,401	138,897	103,318	1,998	2,036	**1,273,804**
DEC	212,770	418,787	1,727	324,352	27,346	108,074	99,992	2,200	2,104	**1,197,351**
TOTAL	**2,627,499**	**5,178,220**	**13,292**	**5,491,664**	**360,106**	**2,102,249**	**1,428,066**	**26,035**	**24,769**	**17,251,902**

Step 3: Parametric Runs and Sensitivity Analysis

In order to reduce the gap between a building's predicted energy consumption and its actual metered data, it is important to determine the sensitivity of the some important parameters of the building (Azar and Menassa, 2012). Hence, parametric reruns of the baseline eQUEST model were done and the changes in the generated outputs were noted and graphically interpreted. The changes were as follows:

- Lighting power density was reduced from 1.2 W/ft^2 (12.9 W/m^2) to 1 W/ft^2 (10.76W/m^2) and 0.80 W/ft^2 (8.6 W/m^2). Figure 7 shows the LPD input wizard screen in eQUEST
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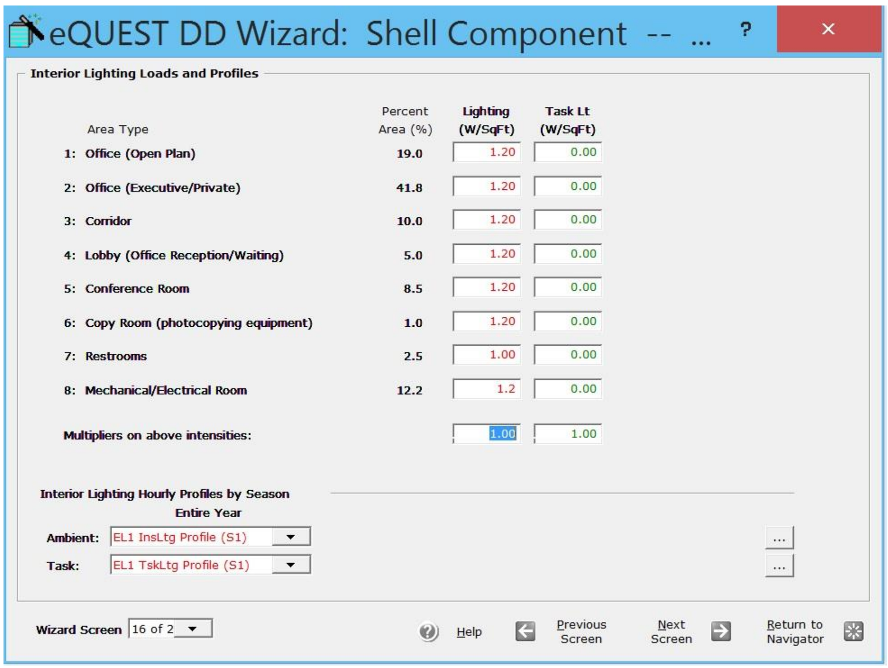
- 

Figure 6: Screenshot of the Lighting Load Input Wizard Screen in eQUEST

- Changing the occupant density from 100 ft^2/person (9.29 m^2/person) to 50 ft^2/person (4.64 m^2/person), 150 ft^2/person (13.93 m^2/person) and 200 ft^2/person (18.58 m^2/person) respectively. Figure 8, displayed below shows the wizard screen to input occupant density in eQUEST. The default value in the program is 100 ft^2 /person.

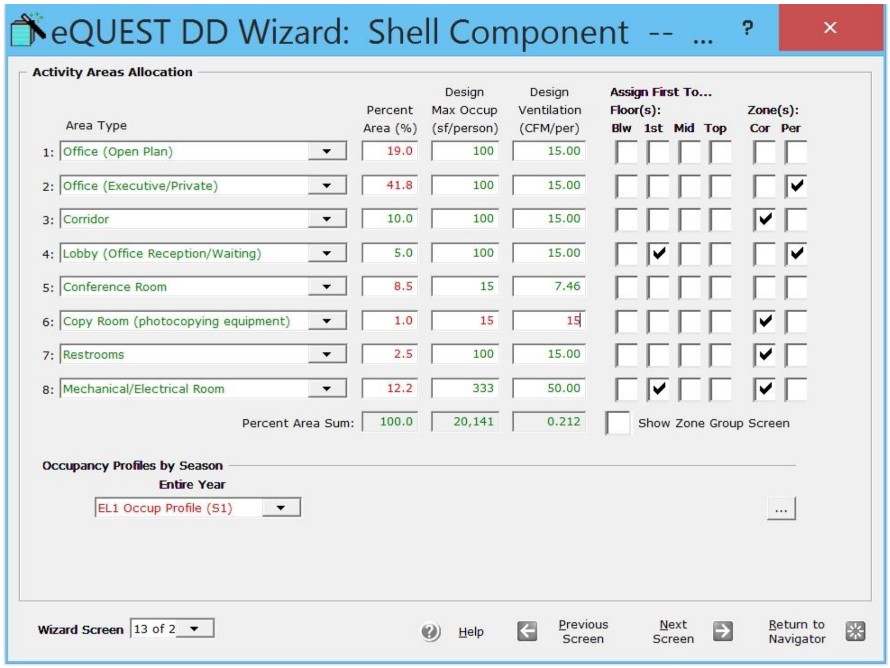


Figure 7: Screenshot of the Occupant Density Input Wizard Screen in eQUEST

- Schedule of the building was changed from zero operational days per week to seven operational days per week, incrementing by one day for each run.
- Changed the weather file from Doha, Qatar to Houston, Texas.

CHAPTER V

RESULTS AND ANALYSIS

5.1 Actual Data Comparison

The case building energy model was simulated in eQUEST using input data from Appendix A. eQUEST provides outputs in two forms: A detailed simulation output file and a summary result/report. A dialogue box to select either output is as shown in Figure 8.

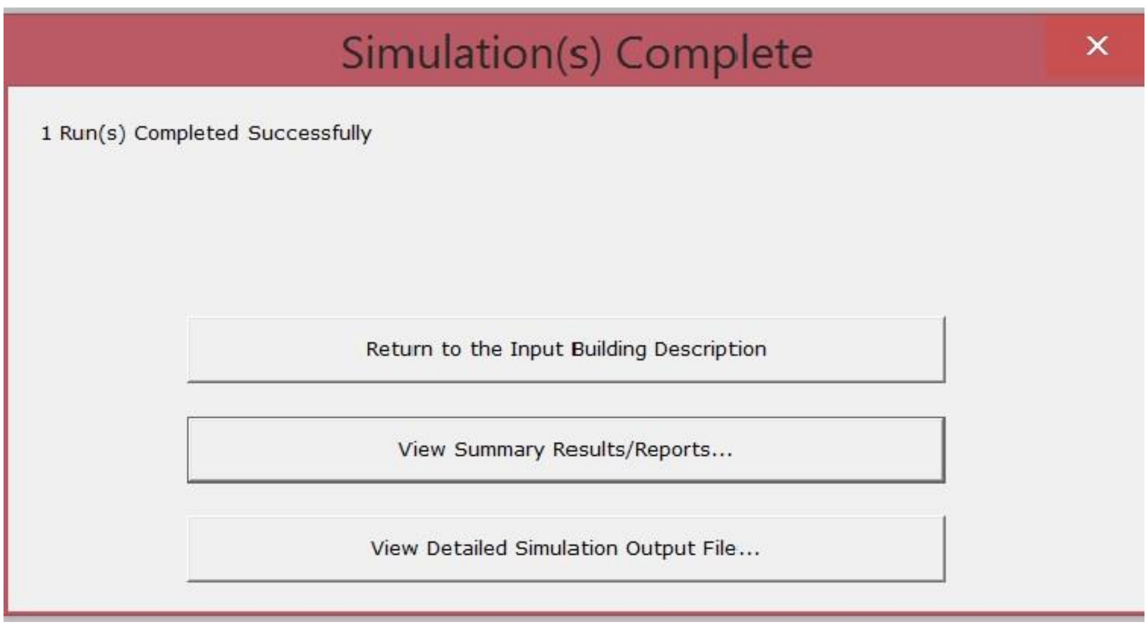


Figure 8: Simulation Output Window in eQUEST

The graphical output in Figure 9 below, is a screenshot from the eQUEST output and displays the energy consumption. eQUEST provides multiple tabs to view monthly energy consumption, annual energy consumption, monthly peak demand and annual peak demand.

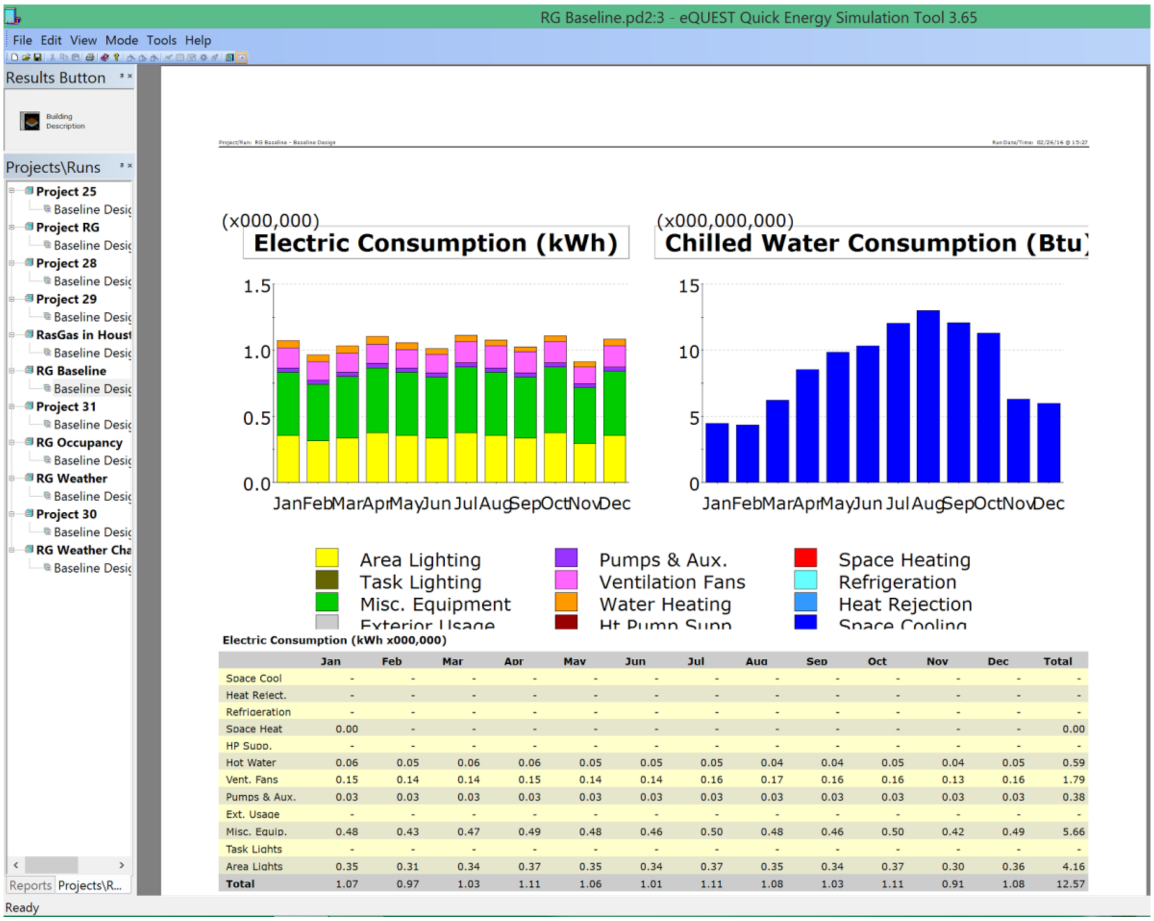


Figure 9: eQUEST Summary Output for the Baseline Design

Table 2 Annual Summarized Actual and eQUEST Baseline Model Results

	Actual	**eQUEST Model Baseline**	**Difference**
Electricity Consumption (in kBtu)	43,065,086.80	42,888,840	0.40%
Chilled Water (in kBtu)	93,767,267.70	104,509,992	-11%
EUI (in kBtu/ft^2/year)	236.5	254.6	-8%

The U.S. Environmental Protection Agency provides a DataTrend series as a part of their ENERGY STAR Portfolio Manager program. This DataTrend series has provided an office building EUI database, which is used as a benchmark for this case building baseline model. Currently, Qatar does not have any such benchmarking program options, so this U.S. based benchmarking database was used for a rough comparison. The median EUI of the U.S database is 187 kBtu/ft^2 (589.91 Kwh/m^2) (DataTrend, 2015). However, both the actual as well as modeled EUI for the case buildings are higher than this average, as seen in Table 2, indicating that the building is consuming considerably more energy than a comparable office building in U.S. The monthly end use energy consumption for the case building are compared in the Table 3.

Table 3: Monthly End Use Comparison of Actual Metered Data and eQUEST Model

Months		Actual (Kwh)	eQUEST Model Baseline (Kwh)
Jan		1,199,679	1,070,000
Feb		1,097,364	970,000
Mar		1,250,464	1,030,000
Apr		1,685,771	1,110,000
May		1,093,100	1,060,000
Jun		574,764	1,010,000
Jul		1,337,157	1,110,000
Aug		1,084,225.00	1,080,000
Sep		1,084,225	1,030,000
Oct		589,621	1,110,000
Nov		589,621	910,000
Dec		1,035,664	1,080,000
Annual Electricity Consumption	**Kwh**	12,621,655	12,570,000
	kBtu	43,065,087	42,888,840

5.2 Peer Model Comparison

The Visual DOE based peer model report provided by AESG was used for comparative analysis to further test the validation of the eQUEST model. The results of the peer model are provided in the Table 4 below.

Table 4: Visual DOE Peer Model v/s Actual Metered Monthly Electricity Consumption

Months		**Visual DOE Peer Model (Kwh)**	**Actual (Kwh)**
Jan		887,806	1,199,679
Feb		815,005	1,097,364
Mar		973,732	1,250,464
Apr		919,929	1,685,771
May		1,044,357	1,093,100
Jun		1,080,330	574,764
Jul		1,049,371	1,337,157
Aug		1,177,968	1,084,220
Sep		1,025,681	1,084,225
Oct		1,015,058	589,621
Nov		897,999	589,621
Dec		872,999	1,035,664
Annual Electricity Consumption	**Kwh**	11,760,235	12,621,655
	kBtu	40,125,921.8	43,065,087

Table 5: Cumulative Energy Consumption and EUI Comparison

	Visual DOE Peer Model	Actual	Difference
Electricity Consumption (in kBtu)	40,125,921.8	43,065,087	-7%
Chilled Water (in kBtu)	18,737,557.6	93,767,267.7	-80%
EUI (in kBtu/ft^2/year)	101.7	236.5	-57%

The comparison in Table 5 shows that the EUI of the Visual DOE peer model is less by 57% from the actual EUI. The peer model was generated by AESG in January, 2012 (AESG, 2012) when the case building had just started operation. The modelers did not have actual data for comparison and modelled the building based on basic building specifications and their engineering judgements. This may have been the primary reason for such substantial difference in the predicted and actual building performance. On the other hand, the eQUEST energy model prepared in this study provided a much accurate prediction (varies by 7%) of the energy performance because of the availability of more comprehensive input data (refer to Appendix A).

5.3 Parametric Runs and Sensitivity Analysis

In order to better understand the impact of some major input parameters, a sensitivity analysis was done. The baseline model was rerun parametrically multiple times by changing the KPIs, namely lighting power density (LPD), occupancy, scheduled operating days and weather. The results were then graphically plotted.

5.3.1 Change in Lighting

The baseline energy model had an average lighting power density (LPD) of 1.2 W/ft^2 (12.9 W/m^2) which is higher than the permissible LPD of 0.90 W/ft^2 (9.68 W/m^2) as suggested by ASHRAE/IES 90.1, 2010 (Dilouie 2011). The baseline model was rerun with LPD values changed from 1.0 W/ft^2 (10.76 W/m^2) to 0.80 W/ft^2 (8.6 W/m^2). The results are shown in the Table 6 and Figure 10 below.

Table 6: Change in Lighting Density

LPD (W/ft^2)	**LPD (W/m^2)**	**Total Electricity Consumption (Kwh)**	**Percent Change from Baseline**
1.2	12.9	12,570,000	-
1	10.76	12,200,000	-3%
0.80	8.6	11,810,000	-6%

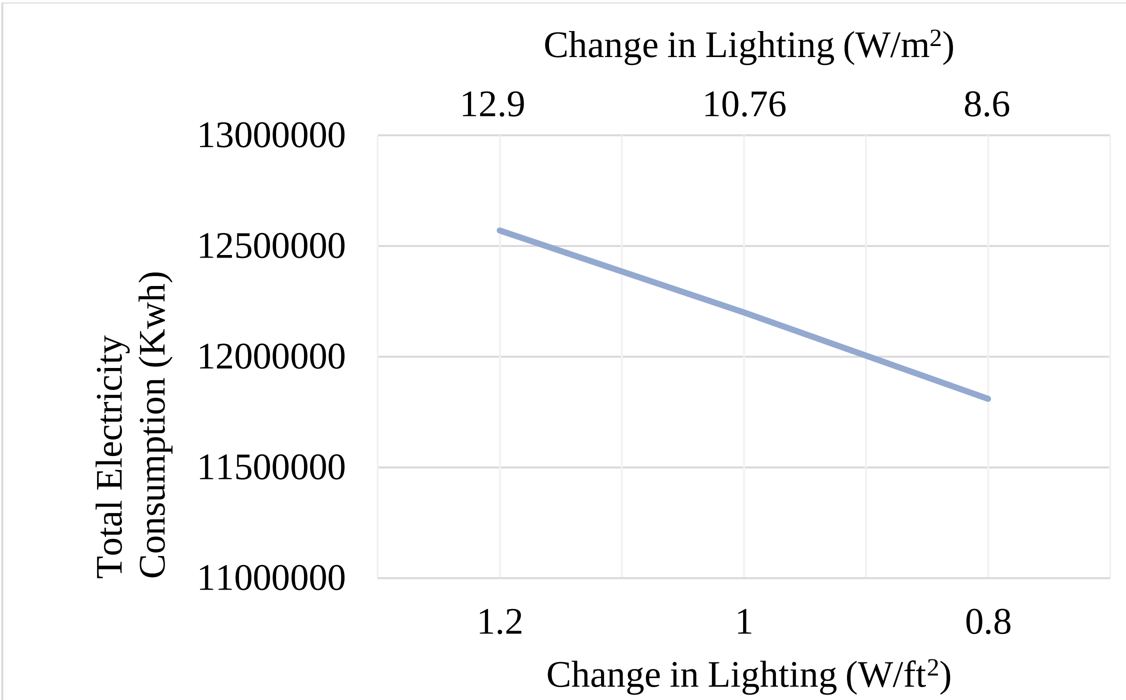


Figure 10: Change in Lighting Density from 1.2 to 1 and 0.80 W/ft^2

5.3.2 Change in Occupancy

Next, the occupant density was altered from 100 ft^2/person (9.29 m^2/person) to 50 ft^2/person (4.64 m^2/person), 150 ft^2/person (13.93 m^2/person) and 200 ft^2/person (18.58 m^2/person) respectively. The results are given below in Table 7 and Figure 11.

Table 7: Change in Occupancy

Occupancy (ft^2/person)	**Occupancy (m^2/person)**	**Total Electricity Consumption (Kwh)**	**Percentage Increase**
50	4.64	13,080,000	-
100	9.29	12,570,000	3.9%
150	13.93	11,960,000	4.8%
200	18.58	10,516,000	12.1%

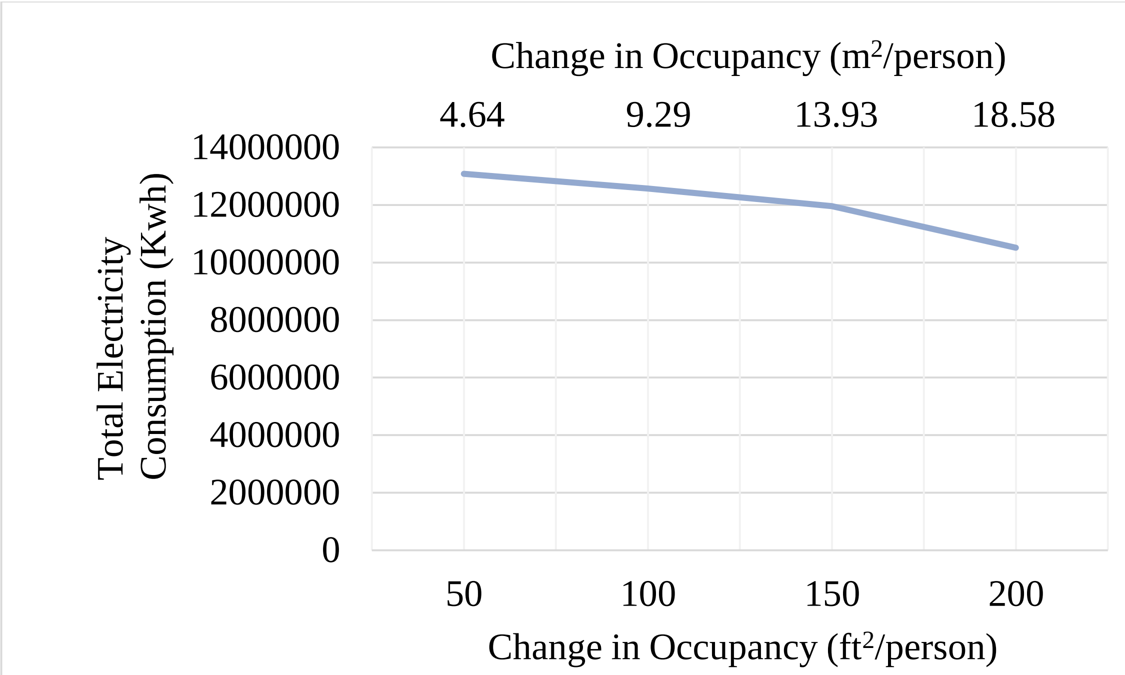


Figure 11: Change in Occupancy Density from 100 to 50, 150 and 200 ft^2/person

5.3.3 Change in Schedule

In order to analyze its sensitivity to changing number of operational days, the days per week for the case building were changed from zero to a maximum of seven. As expected, the graph shows a linear progression in the annual electricity consumption with an average incremental percentage of 22%. The graph is plotted in Figure 12 and the average incremental percentage is shown in Table 8.

Table 8: Change in Operating Schedule (Operating Days/Week)

Schedule (Operational days/Week)	Total Energy Consumption (Kwh)	Percentage Increase	Average Incremental Percentage
0	3,968,000		22%
1	5,902,000	49%	
2	8,005,300	36%	
3	9,918,300	24%	
4	12,330,000	24%	
5	12,570,000	2%	
6	14,080,000	12%	
7	15,160,000	8%	

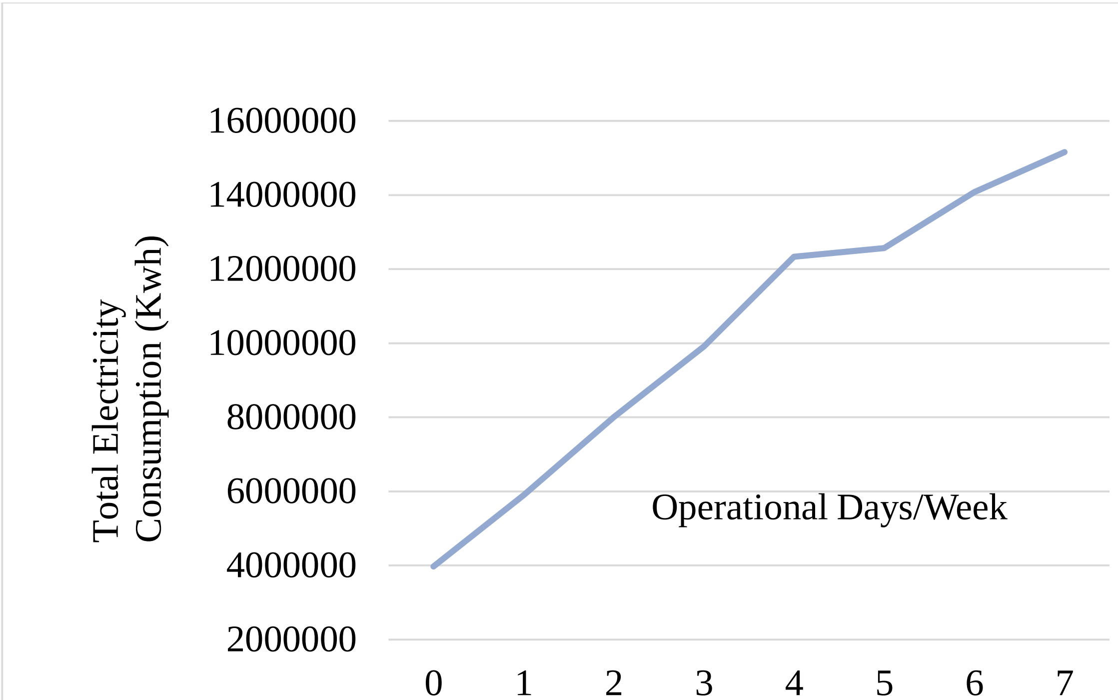
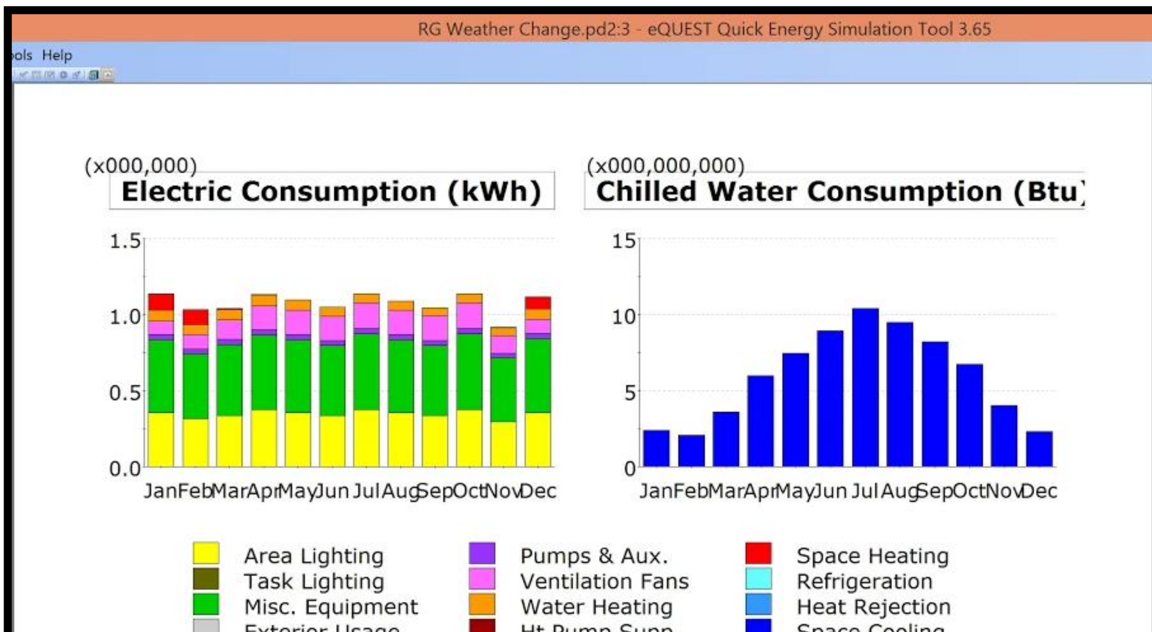


Figure 12: Change in Operating Schedule from Zero to Seven Operational Days per Week

5.3.4 Change in Weather

The sensitivity of the model with respect to change in weather was analyzed by changing the location of the case building from Doha, Qatar to Houston, Texas. The weather file for Houston was obtained from the weather directory folder provided with eQUEST. Houston experiences a humid subtropical (Cfa) climate according to the Köppen Climate Classification System (Koppen, 1948). While Houston experiences mild winters with January being the coldest at an average temperature of 53.1 °F (11.7 °C), the summers are hot and humid summers with frequent thunderstorms. August is generally the warmest month with an average daily temperature of 84.6 °F (29.2 °C) (US Climate Data, 2016).

Doha on the other hand is classified as hot desert BWh (Koppen, 1948) and experiences extreme summers from May through September. As a result the demand for space heating is comparatively low in facilities, as also seen in the case building energy model (refer to Figure 15). Figure 13 shows a screenshot of the output using Houston weather file in eQUEST and Figure 14 shows a graph plotted for the total electricity consumption for case building in Doha and Houston.



Electric Consumption (kWh x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	0.11	0.10	0.01	0.00	-	-	-	-	-	0.00	0.01	0.08	0.30
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	0.07	0.06	0.07	0.07	0.07	0.06	0.06	0.06	0.05	0.06	0.05	0.07	0.75
Vent. Fans	0.09	0.10	0.13	0.15	0.16	0.16	0.17	0.16	0.16	0.17	0.11	0.09	1.66
Pumps & Aux.	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.40
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	0.48	0.43	0.47	0.49	0.48	0.46	0.50	0.48	0.46	0.50	0.42	0.49	5.66
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.35	0.31	0.34	0.37	0.35	0.34	0.37	0.35	0.34	0.37	0.30	0.36	4.16
Total	1.14	1.03	1.04	1.13	1.10	1.05	1.14	1.09	1.05	1.14	0.92	1.12	12.93

Figure 13: Screenshot of the eQUEST Simulation Using Houston Weather File

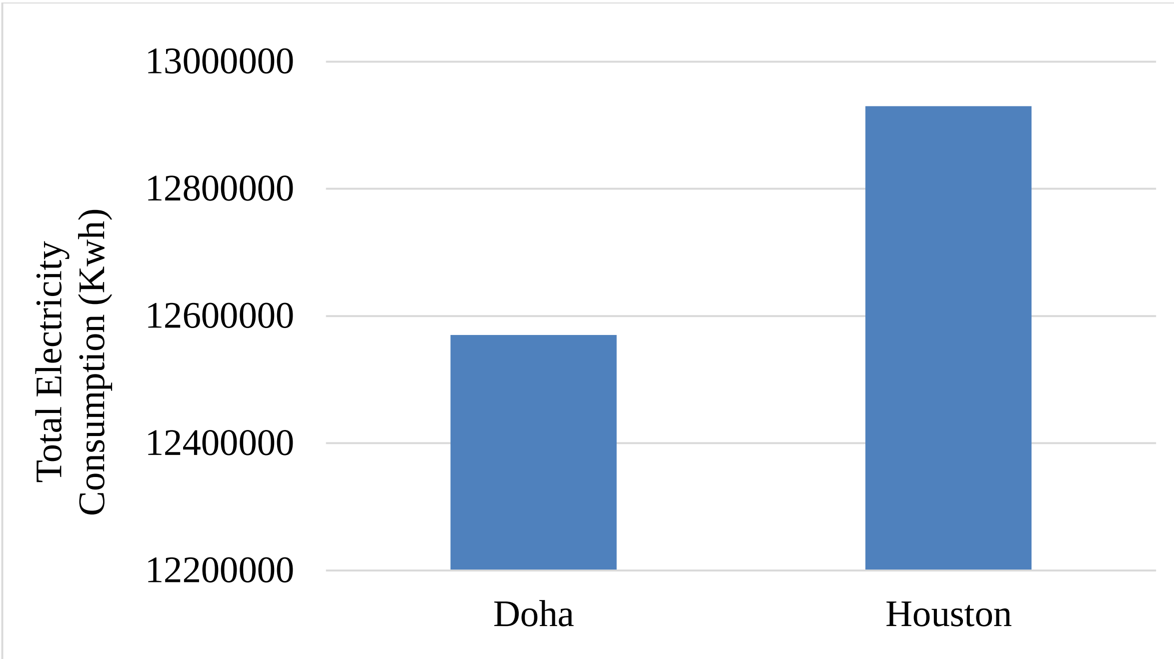


Figure 14: Total Electricity Consumption for Case Building in Doha and Houston

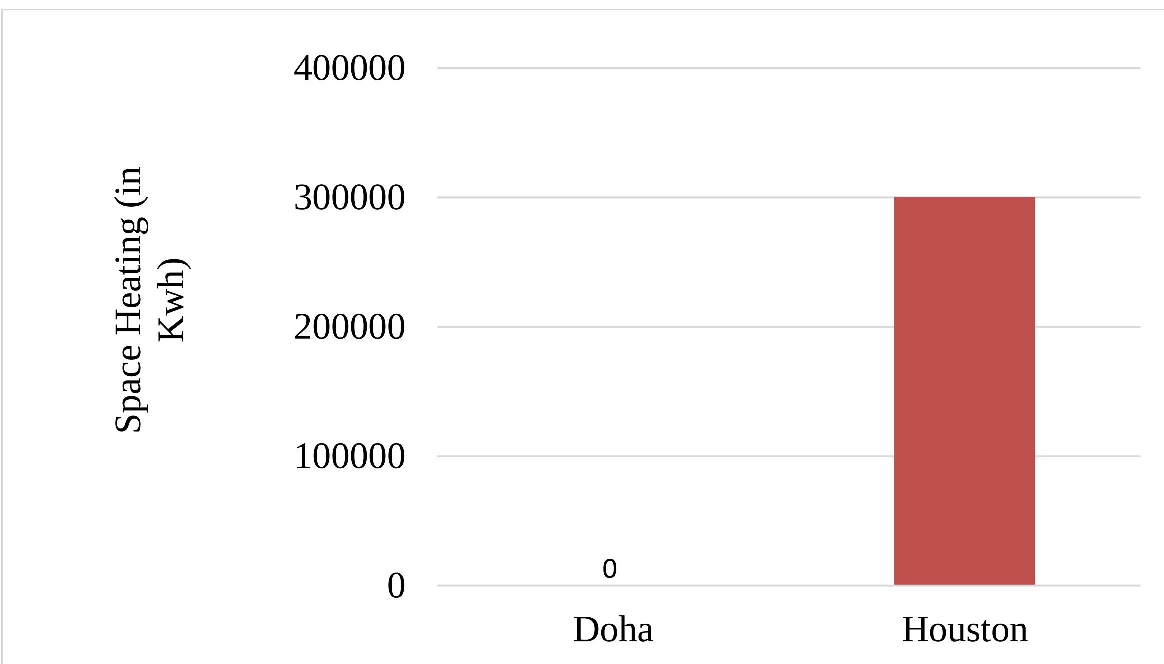


Figure 15: Annual Space Heating Comparison for Case Building in Houston and Doha

CHAPTER VI

CONCLUSION

This research study was an attempted to investigate simplifying the complex and time consuming process of building energy modeling. Through an extensive literature review, the problem Qatar and most Middle Eastern countries are facing was outlined. The energy model generated for the case building in eQUEST shows a minor deviation of 8% in total energy consumption from the actual metered data. This result being in the acceptable range of $\underline{+}$15% (Maamari et al., 2006), validates the model, and also provides a predicted EUI for the building. The predicted EUI as compared with the DataTrend report provided by Energy Star (DataTrend, 2015) shows that the case building is not performing efficiently and the FM for the facility should investigate reasons for such poor performance.

The energy model and actual data were also compared to a Visual DOE based peer energy model. The results indicated that the peer model had substantially underpredicted the building’s energy consumption and provided an inaccurate energy model. The research methods served two purposes; to validate the eQUEST model generated in this study against a peer model and to identify the cause of differences in outputs (if any) from the models. The results of the peer model indicate and confirm that unavailability of comprehensive data in the pre-occupancy phase may result in inaccurate building performance predictions.

Lastly, the sensitivity analysis was conducted using parametric runs in the eQUEST baseline model to identify the importance of lighting, occupant density, operational schedule and weather. The results indicate the following trend:

- The total electricity consumption decreases by 3% on average as the LPD is reduced from 1.2 W/ft^2 (12.9 W/m^2) to 1 W/ft^2 (10.76W/m^2) and 0.80 W/ft^2 (8.6 W/m^2) i.e, approximately by 20%.
- For occupancy, the resulting output also increases with an average increment of 8% per increase of 50 ft^2/ person (4.64 m^2/person) in occupant density.
- The operational schedule is tested for sensitivity by incrementing the number of building operational days per week by one day. The results show an average linear increase of 22% in total electricity consumption per incrementing day.
- Lastly, the effect of weather on the baseline energy model was tested by changing the weather file in the model from Doha to Houston. A 3% increase in the total electricity consumption was noted with significant contribution from space heating.

This qualitative case study is an attempt to provide a base for further research studies in the pursuit of providing energy efficient solutions in the Middle Eastern countries. Developing countries in the Middle East seek to improve the way their facilities are operated and managed. The methodology implemented to seek such goals is easily repeatable by fellow researchers and should open doors to simplifying the method of energy performance predictions.

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APPENDIX

General Information	
Project Name	RasGas Tower, Doha
Building Type	Office Building, High Rise
Jurisdiction	ASHRAE 90.1
Location	Doha, Qatar
Weather File	Doha, Qatar
Analysis Year	2013
Building Envelope	
Building Shell Area	578,616 Ft2
Number of Floors	57 Above Grade
	2 Below Grade
Building Orientation	North East
Floor Height	13 ft (Floor to Floor)
	8.66 ft (Floor to Ceiling)
Exterior Wall Construction	Heavy Weight concrete with polystyrene insulation (R-12)
Roof Construction	Concrete with polystyrene insulation (R-12)
	U factor = 0.1 Btu/(h.sf.F), Roof reflectivity= 0.45 (cool roof)
Roof Albedo / SRI	all glass in tower
Floor/Slab Construction	6" Concert, Ceramic/stone finishes
Ground floor slab Construction	Heavy Weight concrete with assembly
Ceiling	Lay-in Acoustic Tile
Number and Orientation of Main Entry Doors	2 main entry door areas, facing east and west
Type of Main Entry Doors	Swinging glass doors
Dimensions of Entry Doors	6 ft wide x 7 ft tall
Window Category	Double Grey with 1/8in, 1/2 Air
	Double Grey with 1/4in, 1/2 Air
Window Blinds	Roller Shades- Opaque- Medium/ Dark
Building Operating Schedule	Sunday- Thursday; 6am- 6pm
Area Breakdown	Based on percent of 578,616 ft2 of conditioned building area
Open Plan Office	19%

Enclosed Office	41.80%
Corridor	10%
Lobby	5%
Conference Room	8.50%
Copy Room	1%
Restrooms	2.50%
Mechanical/Electrical Room	12.20%
Design Maximum Occupancy (Ft2/person)	Based on percent of 578,616 ft2 of conditioned building area
Open Plan Office	100
Enclosed Office	100
Corridor	100
Lobby	100
Conference Room	15
Copy Room	15
Restrooms	100
Mechanical/Electrical Room	333
Design Ventilation (Ft2/person)	Based on percent of 578,616 ft2 of conditioned building area
Open Plan Office	15
Enclosed Office	15
Corridor	15
Lobby	15
Conference Room	7.46
Copy Room	15
Restrooms	15
Mechanical/Electrical Room	50
Light Power Density (W/ft2)	1.2
HVAC	
Chilled Water	District Chilled Water Supply
Primary System Type	Standard VAVs with Electric Reheat
Supply Fans Power	2.2 WG
Schedule	On 1 hour before and off 1 hour after

Appendix A: Building Input Specifications for eQUEST